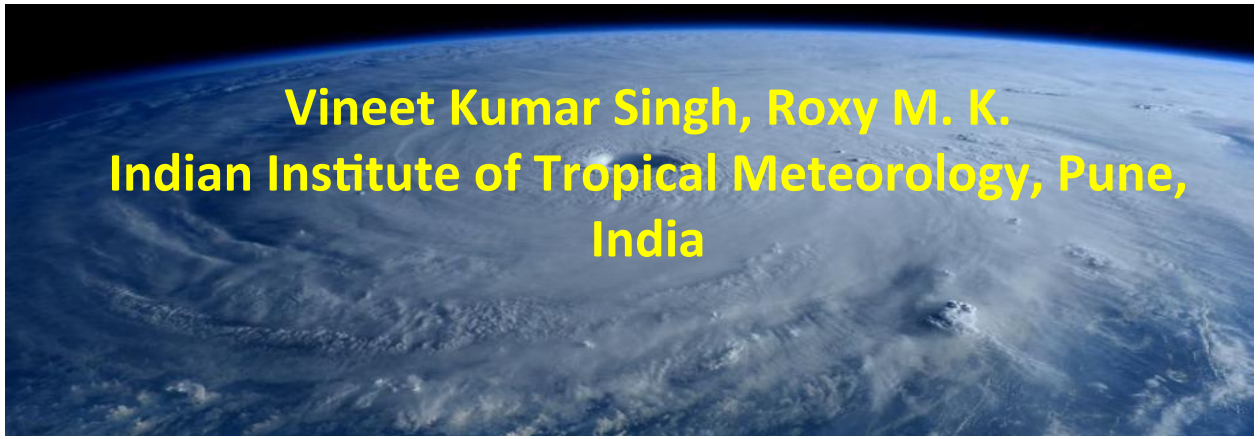
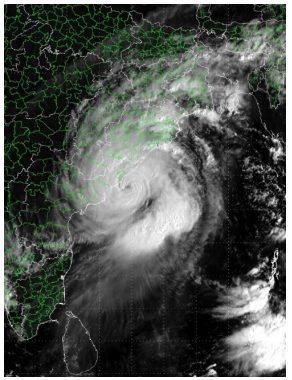
ENSO and Arabian Sea cyclones in a warming climate



Vineet Kumar Singh, Roxy M. K.
Indian Institute of Tropical Meteorology, Pune, India

Tropical Cyclones in Indian Seas

- The North Indian Ocean (including Bay of Bengal and Arabian Sea) accounts for 7% of global tropical cyclones (Gray 1985).
- The cyclone frequency vary between 1-3 in pre-monsoon season to 2-5 cyclones in post-monsoon season (Mandal, 1991) .
- 1~2 cyclone forms over the Arabian Sea per year, (3% of the global total) (Gray, 1968; Singh et al., 2000).



Recent changes in the cyclone activity in Arabian Sea

- Increasing trend in severe cyclonic storms during post-monsoon (period:-1951-2007). No significant increase during pre-monsoon. (Mohanty et al. 2012, Singh et al. 2000)
- During period:-1979-2010, genesis potential has increased, favoring more number of cyclones in this basin during pre-monsoon (Evan et al 2011).
- Increase in intensity of pre-monsoon Arabian Sea cyclones in recent decades (Rajeevan et al. 2013).

Necessary conditions required for Tropical Cyclone genesis (Gray 1975)

- Low vertical wind shear (less than 10 knots)
- High SST (>26.5°C) at least up to a depth of 60m
- Low level relative vorticity (more than 3.5 x $10^{-5}s^{-1}$)
- Coriolis force must be there (away from equator)
- Atmosphere should be conditionally unstable
- High mid tropospheric relative humidity (more than 80%)

- ❖ Are the changes in cyclone activity linked only with local basin changes ???
- ❖ Does large scale phenomena influence the cyclone activity ???

Influence of ENSO on cyclone activity

Tropical Cyclone activity worldwide has known to be affected by El Niño–Southern Oscillation (ENSO) (e.g., Gray 1984; Chan 2000; Chia and Ropelewski 2002)

Arabian sea

- Ramesh et al. (2013) had shown that Arabian Sea cyclones are enhanced during an El Niño Modoki year in both seasons.
- Singh et al. (2000) did not found any statistically significant correlation between Arabian Sea cyclones and ENSO.
- Due to weak ENSO signals in pre-monsoon its influence on Arabian sea cyclones is not properly understood.

Cyclones in a warming world

Projected global change in cyclone frequency

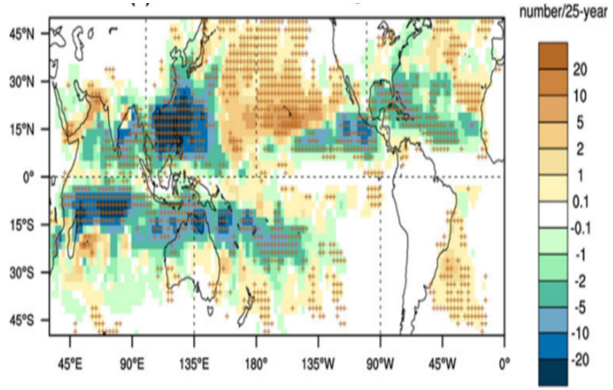


Fig: Ensemble mean future changes in tropical cyclone frequency (number/25 year) for the period (2075-2099) projected by MRI-AGCM (adapted from Murakami et al. 2011)

Projected cyclone genesis frequency change for NIO

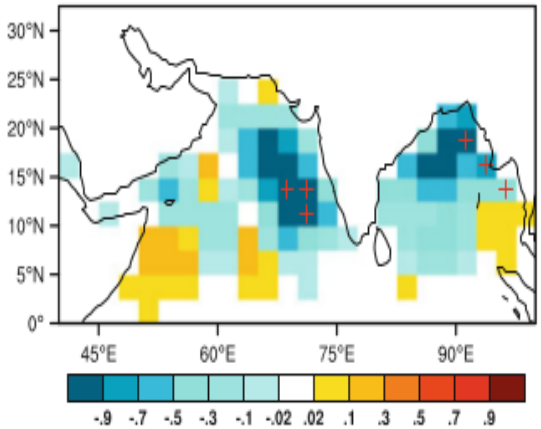
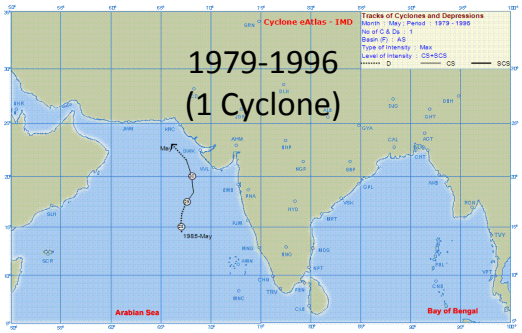


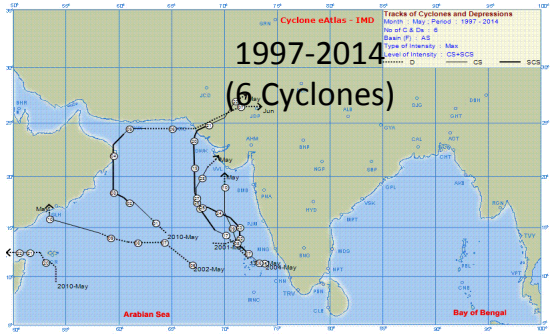
Fig: Tropical genesis frequency change in April and May (10^{-2} number/year) for the period (2075-2099) projected by MRI-AGCM (adapted from Murakami et al. 2012)

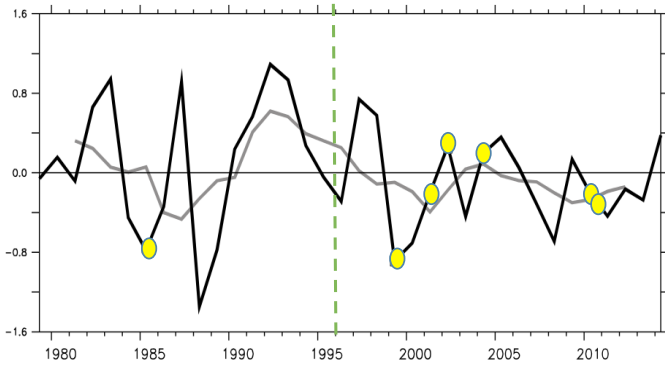
Globally averaged frequency of tropical cyclones is projected to decrease by 6–34% (Emanuel 2010, Sugi et al. 2002).

Recent (1979-2014) changes in cyclone activity in Arabian Sea and Niño 3.4 SST anomalies

7 cyclones formed during the period (1979-2014) in the month of May in Arabian Sea.

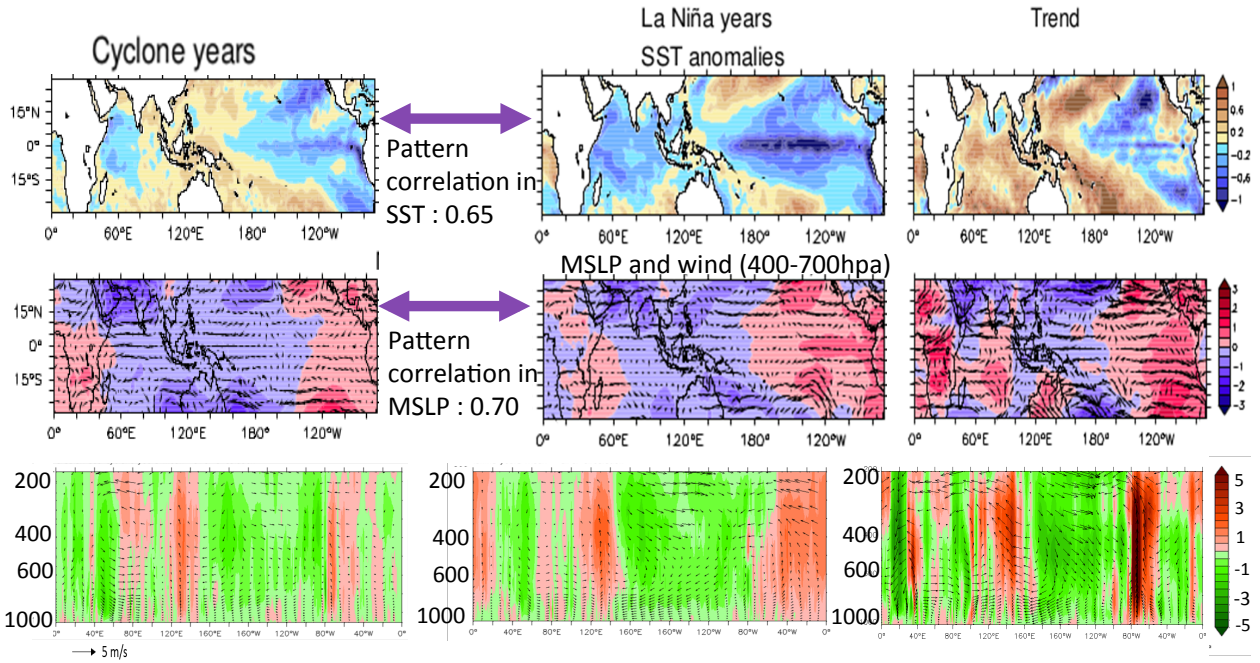






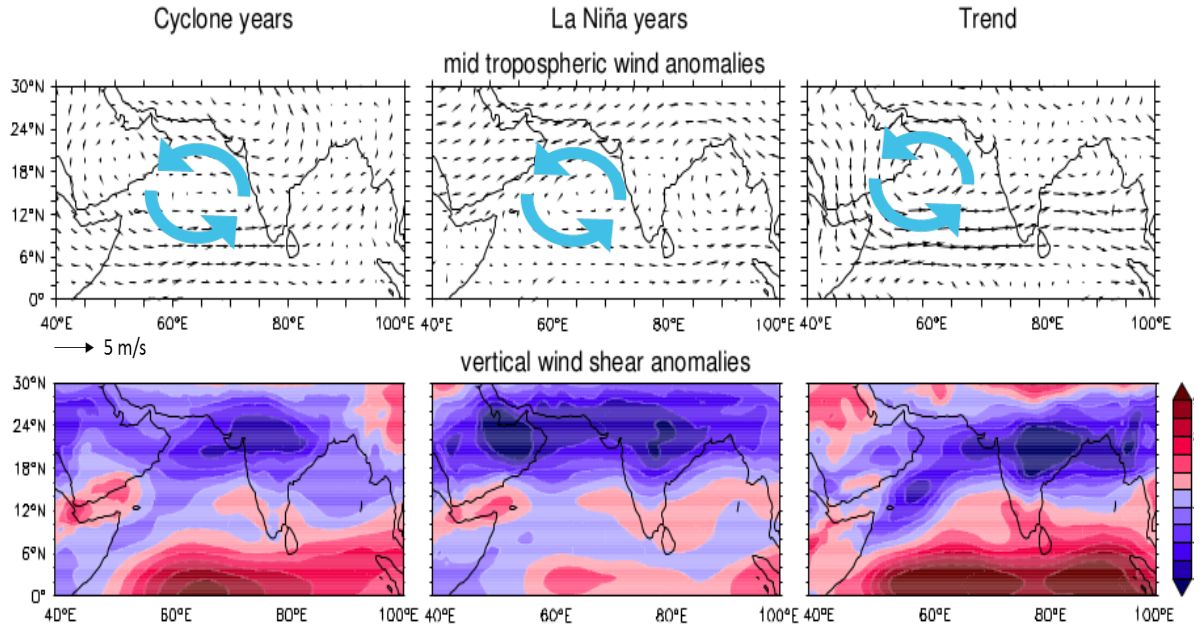
- Out of 7 cyclones, 5 formed when La Niña like conditions persisted in Pacific.
- Decreasing trend in Niño 3.4 region SST indicating more La Niña and negative PDO like conditions during May in recent decades.

Composites of Arabian Sea cyclone year anomalies, La Niña year anomalies and Trend



- SST, MSLP and mid atmospheric circulation pattern anomalies over Indo-Pacific region for cyclone and La Niña years resembles with each other.
- Trend in oceanic and atmospheric parameters are resembling towards La Niña like conditions in recent decades.

Composites of Arabian Sea cyclone year anomalies, La Niña year anomalies and Trend



- Anomalous cyclonic circulation and negative vertical wind shear anomalies over Arabian Sea during La Niña years, resembling with cyclone year anomalies.
- Trend towards cyclonic circulation at mid levels and decreasing shear in the recent decades.

Criteria for selection of best CMIP5 models

The best models are selected based on the following parameters and criteria:

1. Bias in SST in the CMIP5 models, with preference to those models having least bias over north Indian Ocean.
2. Interannual variability in SST (standard deviation) to see which models can capture the ENSO conditions in a more realistic manner.
3. Model skill in reproducing the actual number of cyclones as in observation for the period 1951-2000.

SST bias in CMIP5 models historical simulations (1970-2005)

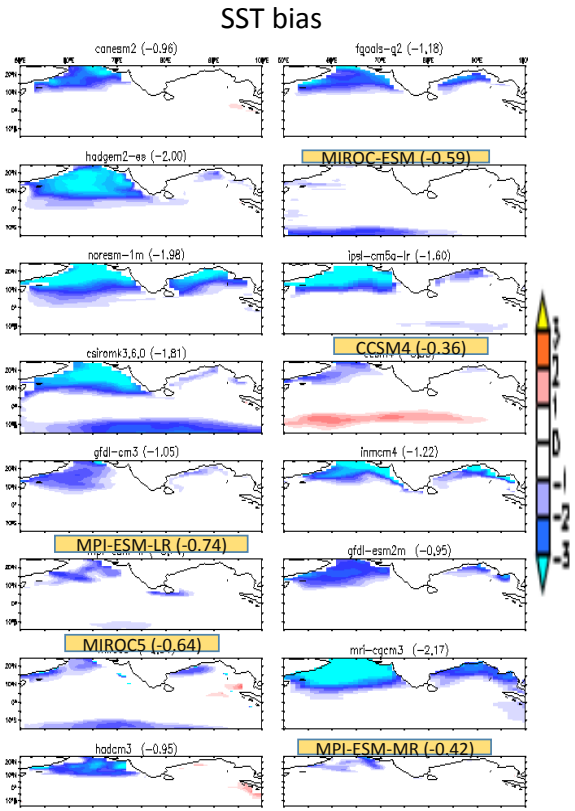


Fig. SST bias(°C) in CMIP5 models. Mean bias for North Indian Ocean (50°E-100°E, 10°S-25°N) is given inside parenthesis

Best selected CMIP5 models

- MPI-ESM-MR
- MPI-ESM-LR
- MIROC-ESM
- MIROC5
- CCSM4

Cyclone detection in best selected CMIP5 models

Method used to identify a model cyclone

- Wind speed at 850 hPa exceeds the ratio of model average wind speed and observed averaged wind speed for the Arabian Sea**.**
- Relative vorticity at 850hPa exceeds 3.5 x 10^{-5} s^{-1}

  Both the wind speed and the relative vorticity thresholds must be satisfied simultaneously for at least two consecutive days.

Table: Threshold for wind speed and vorticity at 850hPa to define a model cyclone

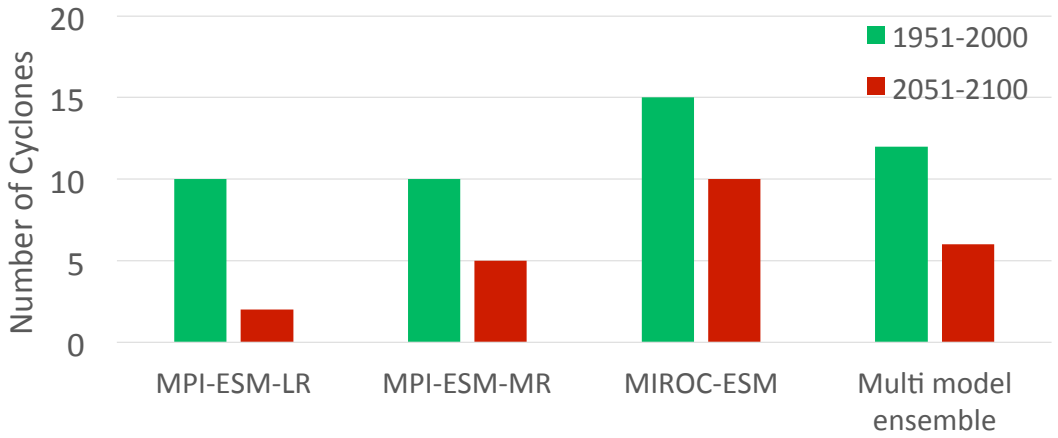
Model	Wind speed (m/s)	Relative vorticity (10^{-5} s^{-1})
MPI-ESM-MR	14.27	3.5
MPI-ESM-LR	16.08	3.5
MIROC-ESM	17.10	3.5
MIORC5	16.68	3.5
CCSM4	12.60	3.5

Table: Number of Cyclones: observation and simulation by CMIP5 models for the period 1951-2000

Observation/CMIP5 models	Number of cyclones for the period 1951-2000
Observation	10
MPI-ESM-MR	10
MPI-ESM-LR	10
MIROC-ESM	15
MIROC5	35
CCSM4	5

MIROC5 is overestimating the number of cyclones and CCSM4 is underestimating the number of cyclones. So these two models are rejected for carrying out the future projections.

Cyclones in CMIP5 models: Historical simulations and future projections

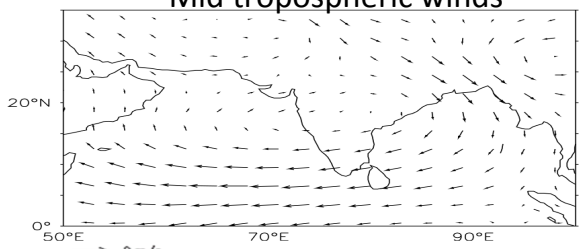


Projected decrease in the frequency of pre-monsoon (May) Arabian Sea cyclone in percentage

- MPI-ESM-MR : 50.0 %
- MPI-ESM-LR : 80.0 %
- MIROC-ESM : 33.3 %
- Multi model ensemble: 50.0 %

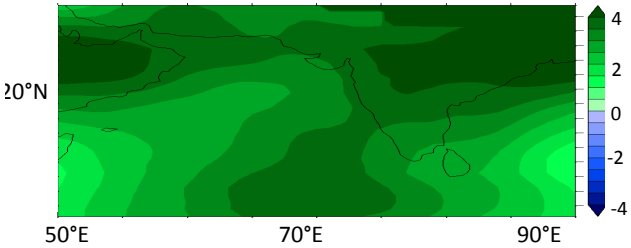
Projected changes in the mid tropospheric winds, zonal wind shear and SST

Mid tropospheric winds



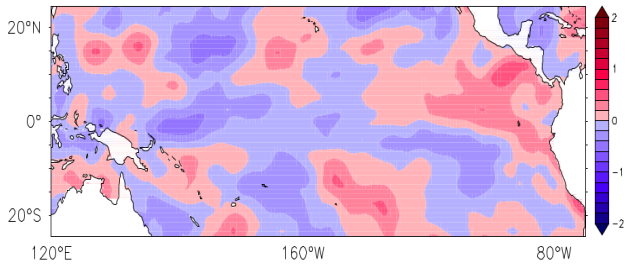
Projected change in mid level atmospheric circulation (700-400hPa) indicates the circulation pattern to become more anticyclonic which will not be conducive for cyclogenesis.

Zonal wind shear



Zonal wind shear (200mb-850mb) is projected to increase which will provide unfavorable conditions for the cyclone to sustain and grow.

SST Skewness



Multi model ensemble is skewed towards El Niño like conditions.

Niño 3.4 SST variability: Historical simulations and future projections

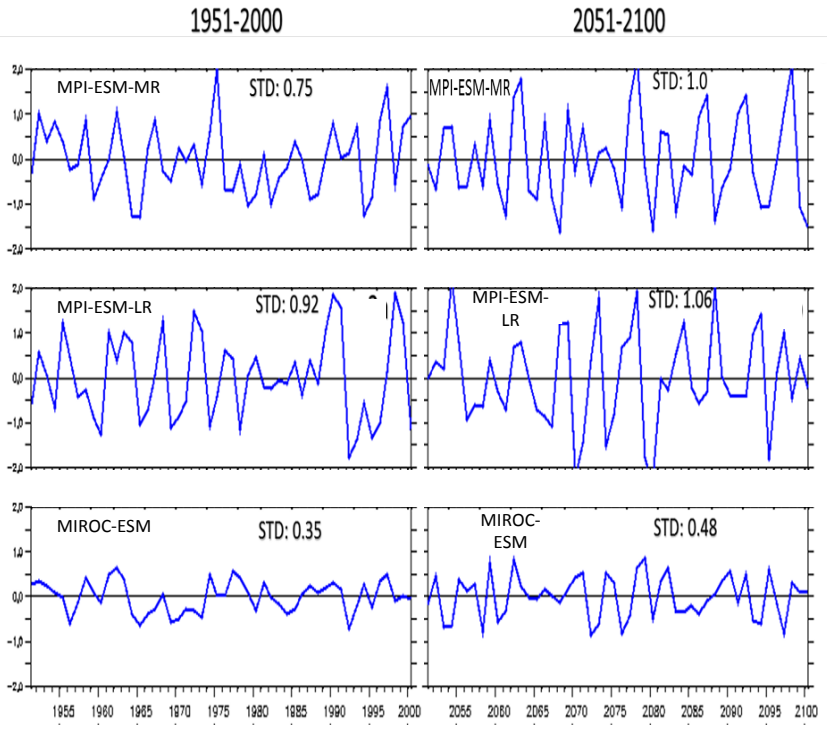
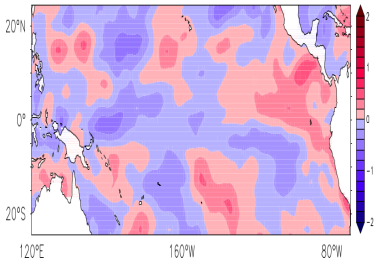


Fig. : Niño 3.4 SST variability historical simulations and future projections by different CMIP5 models.

Projected change in SST Skewness



Multi model ensemble is projecting an increase in the Standard deviation of Niño 3.4 region SST from 0.67 in the historical simulation to 0.85 in the future projections.

This shows enhanced ENSO variability in the future.

Summary

- Increase in the frequency of pre-monsoon(May) Arabian Sea cyclones in recent decades (1979-2014) due to enhanced La Niña like conditions.
- La Niña like conditions changes walker circulation and midtropospheric circulation in such a way that it leads to anomalous cyclonic circulation over Arabian sea providing more conducive atmospheric conditions for cyclogenesis.
- Projections by CMIP5 models estimates a decrease in the cyclonic activity by about 50%.
- This decrease may be due to more El Niño episodes in the future as projected by CMIP5 models
- Enhanced El Niño episodes along with increasing zonal wind shear and unfavorable midlevel circulation over Arabian Sea are the plausible causes for the projected decrease in the pre-monsoon cyclonic activity in Arabian Sea.